Physiology. — "*Our equilibrium-organ*". By Dr. D. J. HULSHOFF POL. (Communicated by Prof. C. WINKLER.)

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When studying the functions of the cerebellum [1]) I always halted before the difficulty of interpretation of the observed phenomena. It is not easy to deduce whether they are dependent on the organ in itself, or resulted from the interruption of tracts in the cerebellum, which took origin in other parts of the central nervous system.

Therefore it seemed to me desirable, before continuing my investigations on the cerebellum, to trace in the first place the connection between those influences which are lying outside of this organ and the cerebellum itself.

As experiments on this subject have often been made, it was clear that repetition of the former investigations would not bring a nearer solution of this problem.

Therefore I resolved not to start by experimenting on animals, but to examine the suffering people and especially to pay full attention to ataxia.

As this phenomenon is often observed by disturbances of the central nervous system and as it is known, that according to the illness, also the decomposition of the movement can show a different type, I thought, that perhaps it could be possible by putting together the different types to get a more distinct insight into the nosology of the cerebellum.

Now it is in general accepted that cerebellar ataxia is caused by a disturbance in efferent paths, and thus could be a motor disturbance, but as this kind of conducting fibres is not well imaginable without afferent tracts, one may accept that these too, interrupted in the cerebellum, will show disturbance in movement.

As my former investigations were exclusively restricted to the motor functions, I thought it now wise to draw attention to the afferent tracts.

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[1]) *Cerebellar ataxia.* Phsych. Neurol. bladen 1909 N°. 4.
Cerebellar functions in correlation to their localisation. Psych.-Neurol. bl. 1915 N°. 3.

Of the sensory and sensorial stimuli which reach the cerebellum along centripetally conducting paths and which are well-known to us, we may mention in the first place the functions of the deep sensation and of the sense for the muscle tone and the equilibrium.

The first pass with the posterior nerve-roots into spinal cord and run partially uncrossed, with the Column of Clark as mid-station, to the tractus spino-cerebellaris dorsalis (FOVILLE-FLECHSIG), while another part, with the area nuclei intermedii as mid-station, run also for more than the greater part uncrossed to the tractus spino-cerebellaris ventralis (GOWER), while a smaller part goes to the same column of the crossed side. This bundle is therefore partially composed of crossed, partially of uncrossed fibres.

The tracts of FLECHSIG and GOWER lie in a long but narrow strip at the lateral edge of the spinal cord and run centripetally.

The tract of FLECHSIG goes through the restiforme body and the inferior brachium conjunctivum towards the vermis of the cerebellum, without coming in contact with the dentate nucleus.

The tract of GOWER does not pass into the restiforme body after having reached the medulla oblongata, but runs on in longitudinal direction. On the level of the nervus trigeminus it bends round in latero-dorsal direction and passes along the brachium conjunctivum cerebelli into the vermis superior and the nuclei tecti cerebelli.

From the posterior columns of the spinal cord however, there are along other paths also tracts connected with the cerebellum, e.g., through the nuclei of GOLL and BURDACH, along the fibrae arcuatae externae and anteriores to the restiforme body and from here to the cerebellum.

As the influence of these latter fibres is far from known, I will leave them in the further discussion out of the question.

Now the experiments of MARBURG and BING [1]) have taught, that the lesion of the spino-cerebellar tracts provokes a very serious disturbance of the statotonus. Partial or total destruction of these bundles from the entrance in the spinal-cord to the cerebellum, will therefore show disturbance of the equilibrium.

If the connection between the tracts of FLECHSIG and GOWER with the cerebellum are well-known, this is less the case with those between the vestibular organ and the cerebellum.

LANGELAAN [2]) writes that the end-arborisation in the oblongata of

[1]) EDINGER. Zeitschr. f. Nerv. Heilk. V. 45, 1912 p. 303.

[2]) J. W. LANGELAAN. Bouw van het centrale zenuwstelsel. Amsterdam. VERSLUYS. 1910.

the vestibular nerve is T-shaped, of which the ascending fibres continue into the cerebellum. They unite into bundles, between which is found gray matter, belonging to the nucleus of DEITERS. These bundles form the greater part of the corpus juxta-restiforme and pass with the fibres of the corpus restiforme into the cerebellum, where they end in the dentate nucleus and in the nucleus tecti. JELGERSMA [1]) too points out (p. 217) the fibres of the nervus vestibularis as thick bundles running through and along the bracchium conjunctivum inferius towards the cerebellum, being everywhere visible as distinct bundles. WINKLER is of a different opinion and thinks from sections, which he possesses, he can make out that the nervus vestibularis does not stand in direct connection with the cerebellum, but that the fibres all end in the corpus juxta-restiforme, around cells of the nucleus of DEITERS, the nucleus triangularis, of the proper nucleus of the radix descendens N. VIII. Cells of middle size, lying in the regions of these nuclei, carry the impulses through the corpus juxta-restiforme towards the cerebellum. It does not receive direct nerve-roots of the N. VIII.

In this case therefore the connection has to take place by means of an interjacent link.

As to the physiological function, the investigators of this region are almost of the same opinion, that the vestibular organ will be *an organ for the muscle tone and for the equilibrium.*

Its great importance for our equilibrium has gradually and regularly come to the foreground, even so, that GOLTZ made a sixth organ of it. [2])

We may say, therefore, recapitulating in short the above mentioned that from the spinal cord as well as from the vestibular organ, strong tracts run to the cerebellum and that interruption of these disturbs the equilibrium.

In my investigations I thought I was allowed to start from the standpoint, even although from both organs paths go to the cerebellum, yet the difference between the stimuli which they conduct, is so great, that it could perhaps show me the way in the intricate mass of the cerebellar phenomena.

Thus, as the spinal path, taking its origin in the peripheral nervous system, enters the spinal cord through the posterior nerve roots and i.a. as the thick posterior fibres of the roots send their collateral fibres to the column of CLARK and the area nuclei intermedii, I thought I could best study the disturbance in the equilibrium when

[1]) G. JELGERSMA. De functie van het cerebellum. Psych. en Neur. bl. 1915.

[2]) H, ZWAARDEMAKER. Physiologie. De Erven F. BOHN. Haarlem 1915. bl. 286.

the centripetal impulses along the tractus spino-cerebellares were fallen away, as happens in cases, affecting the posterior funiculi, e.g. in tabes dorsalis.

For disturbances of the vestibular organ I had best limit myself to those cases, in which the equilibrium organ had lost its functions, inter alia after scarlatina, cerebro-spinal meningitis etc.

In working out these investigations I tried in the first place to devise a scheme, which could serve as well in lesions of the posterior funiculi, as in those of the vestibular organ and in alterations of the cerebellum.

I thought I had found one in letting the patients perform walking-tests, which were registered on paper. For this purpose a line was drawn in the middle of large pieces of paper, on which the patients walked after blacking their footsoles.

When in this paper I leave the results, which I found in cerebellar alterations out of account, and when I limit myself to those which are correlated to lesions of the posterior funiculi and the vestibular organ, I find what follows:

1. If a patient, who suffers from tabes in a rather far advanced state, walks on the paper, then the reproduction of figure 1 [1]) appears:

The patient tries to fulfil the task of walking on the line (foot print 1—2 and 3), but sways to and fro, as in the ROMBERG syndrome and he is obliged to put down the right foot lateralwards, (4). Still worse the swaying becomes in the following right footstep (6) when he replaces the foot three times to keep his equilibrium.

The deviation in the line of equilibrium is most distinct with the footsteps 8 to 11, which he had to put down close to each other and during which it was impossible to him to remain on the line. He therefore leaves off trying it and walks on rather well along a broad gait-path.

2. When that which is ordered sub I, is repeated, but with eyes shut, then the deviations of the gaitpath are still more districtly visible.

3. If one lets the patient repeat the same walking exercises as sub 1 and 2, but allows him at the same time to touch our hands [2]), then one sees a gaitpath nearly as normal (fig. 2).

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[1]) The cross on the photo indicates the moment when I thickened the contours of the foot prints with ink, because otherwise the footsteps do not come out well enough on the photograph.

[2]) While walking the patient, who is standing on the middle of the paper, stretches his arms to the left and to the right and lays his hands on the dorsal plane of those, which are tended to him from the side. The persons, who help to

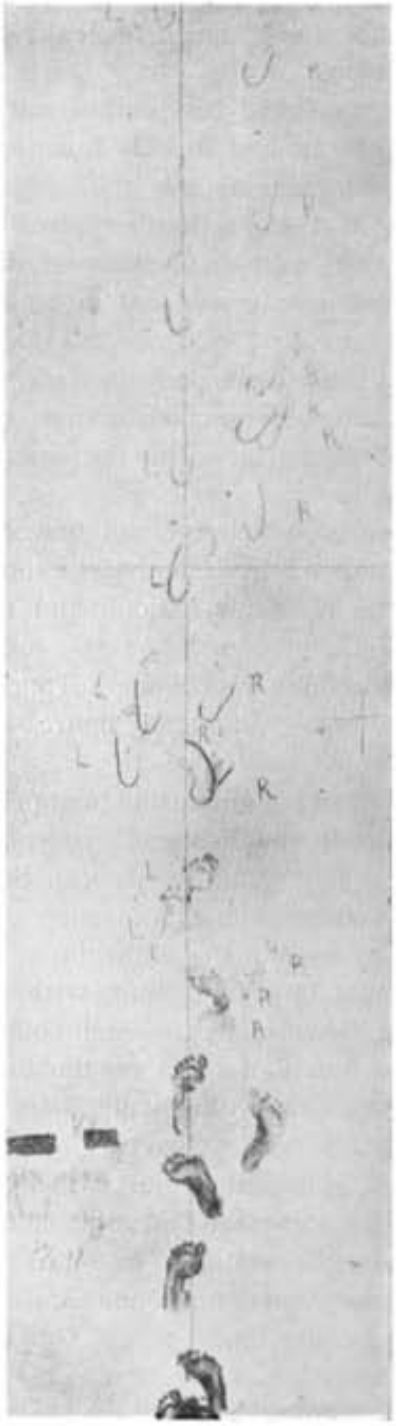

Fig 1.
Tabes no contact-sensation.

Fig. 2.
Tabes contact-sensation.

Fig. 3.
Vestibular affection no contact sensation.

Fig. 4.
Vestibular affection contact-sensation.

4. If one reproduces of a patient, suffering from a vestibular inflection, a gait-path, then distinct deviations will be visible (fig. 3).

5. If we repeat the experiment, but with eyes shut, then the deviations sub 4 are more distinctly visible.

6. If we allow the vestibular suffering patient to touch our hands, then one gets a very important amelioration, even a nearly abolished ataxia (fig. 4).

If the symptoms which these patients show are put together, then we have three types:

a. distinct deviation while walking with open eyes, while the hands do not find contact.

b. increasing of these deviations, when the eyes are shut.

c. gait nearly normal, at least important improvement of it, when the hands find contact.

If one wants to comprehend these three differences well, then it is necessary to bring to the foreground that our movement equilibrium, as it were, is principally regulated by the eyes, the vestibular organ and the equilibrium sensation [1]) of the trunk and the lower limbs.

Of these three factors the eyes are the least important, which is easily tested by the fact that a person can walk very well with his eyes shut, but directly shows disturbances, when the vestibular organ or the equilibrium sensation are suffering. This can also be explained, because the last two factors give proprioceptive stimuli, according to the particular conception of SHERRINGTON, which do not affect consciousness, while the eyes convey exteroceptive stimuli, with regard to the gait. We could describe it best in this way, that the equilibrium is governed by the vestibular organ, also by the equilibrium sensation of the trunk and the limbs, while the eyes only regulate the intended direction of the movements.

Therefore when a patient suffering from tabes walks, he does not wholly dispose of the three above mentioned factors, but he walks, if we are allowed to express it thus, by his eyes, by the vestibular organ and the rests of the equilibrium sensation of the trunk and the legs. The result is, that the movements become uncertain. If such a person shuts his eyes, then the exteroceptive stimuli, moreover,

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do this and *who walk along the edge of the paper*, are asked *not to support* the patient, but to give way as it were in vertical direction to the movements, which the patient makes. Their hands therefore have to balance too. The patient has no support, but only contact sensation with the persons who walk alongside of him, and by which his equilibrium sensation can orientate itself.

[1]) Equilibrium sensation has to be interpreted as an independent subdivision of that, which till now is brought together in conception of "deep-sensation".

fall out, because the eyes cannot give direction to the intended movements and therefore it is comprehensible that the uncertainty of the gait augments.

However on the other hand it can be said that as the equilibrium in particular is only regulated by proprioceptive stimuli, disturbances in gait will occur, when a part of those fall out, but the disturbances will be partially improved by the exteroceptive stimuli, which by means of the eyes can convey their stimuli.

The above mentioned is known, but it is most important, that when to such a tabes patient, either with opened, or shut eyes, *contact* is given through persons walking alongside of him, the gait greatly improves, even so, that the ataxia nearly altogether disappears.

As such a patient is *not supported,* but as he has only *contact* with persons walking alongside of him, I think it may be assumed that the equilibrium sensation of the upper limbs is put into action. The equilibrium-sensation orientates itself along this new path, brings in this way new afferent proprio-ceptive impulses towards the central nervous system and therefore it can better control the movements of the lower limbs. The equilibrium sensation of the arms, in the tabes patient, thus takes over the function of the equilibrium sensation of the lower limbs and trunk (this only of course when the tabes is present in the caudal part of the spinal cord), which for a great part has disappeared.

Therefore we can say the following:

a. a tabes patient walks by his eyes, by the vestibular organ and the *rests* of the equilibrium sensation of the trunk and the legs.

b. if such a patient has contact-sensation with persons walking alongside of him, then he *moreover* walks by the equilibrium sensation of the arms.

In case *a* he lacks afferent equilibrium impulses on a great scale and therefore he walks atactic, in case *b* the amount of these equilibrium-impulses is very considerably augmented and the ataxia therefore is improved, nay it even has entirely or almost disappeared.

If we have a patient suffering from a vestibular affection, then we see on the whole the same effect.

In this sort of patients the central nervous system too receives the exteroceptive impulses by way of the eyes, and moreover the proprioceptive ones of the trunk and the legs, through the posterior roots of the spinal cord, but none or only partially from the proprioceptive ones of the vestibular organ.

The result of this is, that the amount of equilibrium impulses is not sufficient, therefore the patient walks atactic.

For these cases too it is important, that when the patients, by means of their arms, receive equilibrium contact through persons walking at their side, then the ataxia either very importantly improves or it entirely is abolished.

Here too we see, that the equilibrium contact of the arms replaces totally, or for a very large amount the proprioceptive impulses from the vestibular organ.

Therefore we can say for this case:

a: a vestibular patient walks by his eyes, by the equilibrium sensation of the trunk and the legs, and the afferent-proprioceptive stimuli from the vestibular organ, which is left to him.

b: if such a patient has equilibrium contact with persons leading him, then he *moreover* walks by the equilibrium sensation of the arms.

In case *a* he lacks afferent equilibrium stimuli and the patient walks atactic. In case *b* the ataxia totally or partially disappears, because his lack is supplied.

Now the peculiarity of the results found is, in tabes as well as in vestibular affection, *that the equilibrium sensation of the arms can compensate the equilibrium sensation of the trunk and legs as well as the impulses from our vestibular organ.*

On account of this the question arises whether it is possible, that in our equilibrium different organs can replace each other.

This question deserves to be answered in the affirmative to a certain extent.

If e.g. we close the eyes of a person, who is then asked to walk straight on, there will be many, who deviate to the right or to the left. The reason of it will depend among other things on the fact, that the proprioceptive equilibrium stimuli, which arise from both the halves of the body, are not of the same strength; the result is that one half predominates and that the gait will not be totally straight. If we place, however, at a distance a person, who counts, then the blindfolded person will be able, guided by the sound, to walk straight on towards the counting person. The extero-ceptive stimuli, which pass from the ears towards the cerebrum, complete the others, through which the straight gait is made possible. The sense of hearing comes to the aid of the equilibrium sensation. It is also well-known that the eye sense can give direction to our movements.

It is comprehensible that as these two senses are already able to give assistance under normal circumstances to the equilibrium sensation, they can help the suffering person in yet higher degree after practice.

It is also a well-known fact that e.g. the ataxia in tabes patients, who can still walk straight with their eyes opened, comes to the

foreground, when the same movements are performed with eyes shut, or when they are walking in the dark and cannot make use of their eyes.

This help may be rather sufficient in light cases of tabes, but it will not be possible to totally improve the disturbance, if the illness has become of a rather serious nature. If we give to this kind of patients contact-sensation by the arms, there will yet be an important improvement. (Fig. 2).

Consequently from this follows as is moreover near at hand, that the equilibrium sensation of the arms, being of the same sort as of the trunk and limbs, compensates in reality, while the other senses can only correct to a certain degree.

I have pointed out in the preceding pages, that one finds the same facts back in lesions of the vestibular organ. Here too the ataxia improves, when the patient uses his eyes (Fig. 3), but here too one finds, that *when the eyes cannot sufficiently correct any more, the ataxia totally or nearly totally vanishes, when through the arms equilibrium-sensation is obtained with the surrounding world.* Here too we find, that the equilibrium sensation of the arms acts totally or nearly totally compensatory. (Fig. 4).

The question arises how we can explain this.

I think that I may except as easy to comprehend, *that the proprio-ceptive stimuli of the equilibrium sensation of the trunk and the limbs and those of the vestibular organ are to be considered of the same sort.*

Referring to our equilibrium, no difference should be made between the afferent-proprioceptive stimuli, which from the vestibular organ are conducted to the central nervous system and those which come there from the trunk and the limbs. It is a large system of equilibrium fibres that is spread over our whole body and its aim is to regulate the equilibrium.

The sixth sense, the one for our equilibrium, has therefore not only to be looked for in the vestibular organ, but it is, as I explained, spread over the whole of our body. The vestibular organ is but a part of it.

Now probably one might ask, why does that organ form a whole while in the other equilibrium paths very little independency is found. The reason for this, according to my view, has to be found in the extraordinary relation of the head, in comparison to the rest of the body.

To make this clear, one has to keep in mind, that the equilibrium sensation of the different parts of our body is not everywhere the same, or otherwise expressed, is no teverywhere equivalent. E.g. the equilibrium sensation for the trunk, which can only move

moderately, is but little developed. For the lower limbs it must be already higher, because the movements which they perform are already much more complicated.

In yet higher degree this is the case with our arms. So it is known, that as soon as our equilibrium gets in any danger, we do not only immediately put our arms into function, but that we trust even more to our arms, which are weaker concerning our muscle strength than to our much more muscular legs. If the equilibrium sensation of our arms has already reached a high degree, this will be yet more so with our head, which is above all designed to bring to our knowledge our attitude in space. It speaks for itself that without this knowledge no equilibrium is possible. Moreover, with exception of the lower jaw, the different parts of the head are not linked together by joints, but they are tightly grown together. That this puts the head into an extraordinary relation is comprehensible. The trunk and the limbs are in opposition to the head composed of movable parts, which are joined together by tendons and sinews. All the changes in attitude, therefore also those which are of importance for our equilibrium, come to our consciousness. This is not the case with our head.

By means of the neck and all that is connected with it, it can, however, fix its own *posture* with relation to our body, but it will not be of any use for the determination of the equilibrium.

The equilibrium organ of the head has, on account of what was above reported, to be not only much more highly developed, but it must be differently composed from the equilibrium paths for the trunk and the limbs. Therefore too the vestibular organ is built up in a different way. As the joints in our head, necessary for the equilibrium, are all missing, it is most probable, that the statoliths through movements during the changes of attitude stimulate the equilibrium fibres aud thus put into action the necessary afferent-proprioceptive impulses. The central nervous system is immediately warned of any danger that threatens our equilibrium and can take the necessary steps against it.

CONCLUSIONS.

a. The sixth equilibrium sense is not placed in the vestibular organ only, but has its tracts spread over the whole body.

b. The vestibular organ is, as far as it refers to our equilibrium only to be considered as a part of the equilibrium sense.

c. The different parts of this sense can compensate each other reciprocally.